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AN EVALUATION OF HEART RATE RESPONSE TO EXERCISE  
ON THE CONSTANT WORK LOAD BICYCLE ERGOMETER

by

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A THESIS

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UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled, "An Evaluation of Heart Rate Response to Exercise on the Constant Work Load Bicycle Ergometer," submitted by Peter John Carroll in partial fulfilment of the requirements for the degree of Master of Science.



## ABSTRACT

The purpose of this thesis was to investigate the accuracy of the Elema-Schölander constant work load bicycle ergometer. This ergometer is built according to the design of Holmgren and Mattsson (18), and maintains a constant work load ( $\pm 5\%$ ), provided the pedalling frequency is between 45 rpm and 75 rpm, regardless of whether a constant pedalling rate is maintained.

The main problem was to determine whether the physiological responses of heart rate and respiration rate are constant regardless of pedalling rate. Subsidiary problems investigated the effect on these parameters of varying pedalling arm lengths, varying work loads within the prescribed accuracy of the ergometer, and the reliability of the ergometer to two test performances at a constant pedalling rate.

This study investigated the following null hypotheses: that there is no difference in the means of the heart rate and respiration rate responses to exercise of three trials at varying pedalling rates within the accuracy of the machine; that there is no difference in the means of the heart rate and respiration rate responses to exercise of two trials with varying pedalling arm lengths on the machine; that there is no difference in the means of the heart rate and respiration rate responses to two work loads selected from the limits of the prescribed reliability of a third work load on the machine; and that there is no difference in the means of the heart rate and respiration rate responses to exercise of two trials at a constant pedalling rate on the machine.



Forty-eight healthy male subjects aged from nineteen to thirty years participated in the study, the total sample being comprised of volunteer students from the University of Alberta, Edmonton. Subjects were randomly allocated to groups and were assigned to trials within each group in different experimental order. A five minute rest period preceded each test. Heart rates and respiration rates were recorded continuously throughout the experiment. Steady state heart rate was taken as the average of the 5th and 6th minutes of exercise provided these values did not exceed  $\pm 5$  beats per minute.

Within the limits of the sample tested and the reliabilities of the experimental procedure employed, it was found that exercise at different pedalling rates within the prescribed accuracy of the ergometer elicits different steady state heart rate and steady state respiration rate responses. The results of the subsidiary investigations led to the following conclusions: that changing the pedalling arm lengths within the limits of the present adjustment of the ergometer does not affect the steady state heart rate and steady state respiration rate responses to submaximal exercise; that work loads chosen from the limits of the prescribed accuracy of the ergometer at 1000 kpm/min. indicate that the ergometer is sensitive enough to distinguish a 100 kpm/min. difference, but not sensitive enough to distinguish a 50 kpm/min. difference; and that the ergometer provides reliable results to exercise tests when pedalled at a constant rate.





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## CHAPTER I

### STATEMENT OF THE PROBLEM

#### Introduction

In recent years lack of physical fitness has been mentioned frequently in the public news media. It has been reported that North Americans are less fit than Europeans, and particularly that North American children are not able to run, jump, and perform as well as their European counterparts (12,21,27).

Authorities in physical education and other fields are unable to agree as to what physical fitness is, or how fit an individual should be. A review of this question is given by Norman (26). The focussing of attention upon physical fitness has led to efforts by physical educators to ascertain the level of fitness prevailing in the general population so that a basis for future developments may be established. In Canada, the Canadian Association for Health, Physical Education and Recreation is currently establishing norms for children aged from seven to seventeen years on a motor performance and fitness test, and is also preparing to evaluate physical fitness by establishing norms for a physical work capacity test.

The large number of general methods and specific tests used to study exercise fitness suggests that no single test is completely satisfactory. Usually, the response of an individual to a stress which exceeds that in the resting state is measured in order to assess the





current status or to predict reaction to still other situations (24). Thus, physical work capacity tests and tests of physical fitness are being used to determine the present level of fitness. A number of these tests are performed on bicycle ergometers which have been shown by several investigators (7,11,24,31,33,34) to have many advantages when appraising physical performance.

This study attempts to evaluate the reliability of a new type of bicycle ergometer that is reported to overcome some of the problems of earlier ergometers.

### The Problem

The heart rate response to six minutes of exercise on an Elema-Schölander constant work load bicycle ergometer was investigated. This ergometer, which is built according to the design of Holmgren and Mattsson (18), is considered to maintain a constant work load ( $\pm 5\%$ ), provided the pedalling frequency is between 45 and 75 rpm, regardless of whether the subject is able to keep up a constant pedalling rate.

The problem was to determine whether the physiological parameters, as measured in established physical fitness tests, are constant, regardless of pedalling rate. Specifically, the study determined whether the respiration rate response and the heart rate response were constant at different pedalling rates within the prescribed limits of the ergometer.

### Sub-problems

1. To determine the effect upon the measured physiological responses of a maximum and a minimum pedal position along the pedalling arms.





2. To determine whether there is any significant difference between the measured physiological responses of two work loads selected from the limits of the prescribed reliability ( $\pm 5\%$ ) of a third work load.
3. To determine the reliability of the ergometer to two test performances at a constant pedalling rate.

### Hypotheses

The following null hypotheses were investigated:

1. There is no difference in the means of the steady state heart rate and the steady state respiration rate responses to exercise of three trials at varying pedalling rates within the accuracy of the machine.
2. There is no difference in the means of the steady state heart rate and the steady state respiration rate responses to exercise of two trials with varying pedalling arm lengths on the machine.
3. There is no difference in the means of the steady state heart rate and the steady state respiration rate responses to two work loads selected from the limits of the prescribed reliability of a third work load on the machine.
4. There is no difference in the means of the steady state heart rate and the steady state respiration rate responses to exercise of two trials at a constant pedalling rate on the machine.

### Importance of the Study

The bicycle ergometer fits the criteria suggested by Rodahl and Horvath (28) for a measurement of exercise fitness: large muscle groups are used, the work load is measurable and adjustable, results are comparable for a given individual under different conditions, between



individuals, and for different groups. The adjustable seat height and size allows constant mechanical efficiency for both trained and untrained subjects. These views agree with those of Adams et al (1), Bengtsson (11), Tuttle and Wendler (32), and Wahlund (34).

Bicycle ergometers which have been constructed by various investigators in the past have generally been of two types. A friction brake is used in some models, while others employ the principle of the electrodynamic braking action of the electrical generator. The friction model is widely used and requires the subject to maintain a constant pedalling rate, otherwise a correction is necessary to determine the work load. Earlier models of the electric bicycle also required a constant pedalling rate from the subject but subsequent development has removed this restriction.

If this study can show that the physiological responses are not significantly different when there are variable pedalling rates, the value of this type of ergometer is increased for use in tests of physical fitness and physical work capacity. Two of these tests, which are widely used in physical education, are the Modified Sjöstrand Physical Work Capacity Test (36) and the Astrand-Ryhming Predicted Oxygen Intake Test (3).

In the Sjöstrand Test subjects pedal for three consecutive six-minute periods, at variable work loads. The first work load is selected so as to result in a steady state heart rate of between 120 and 130 beats per minute. The second and third work loads are adjusted on the basis of the heart rate response to the initial work load so that the final





steady state heart rate is as close as possible to 170 beats per minute. Heart rate is recorded at the end of each minute and the steady state heart rate is taken as the average of the 5th and 6th minute within each work load. A regression analysis is used to calculate the work load level for 170 beats per minute. This value is called the  $PWC_{170}$ .

The Astrand-Ryhming Predicted Maximal Oxygen Intake Test is a test which predicts maximum oxygen intake from the heart rate response to six minutes of exercise. This prediction is implemented with the aid of a nomogram developed by Astrand and Ryhming (3).

In both of the above tests actual work load is important in determining the final values. When a friction brake ergometer is used, the work load depends upon a constant pedalling rate, which, if not maintained, introduces an error. This error is likely to occur when the resistance nears maximum, or when a subject becomes fatigued. The aim of this study was to determine whether the constant work load bicycle ergometer could overcome this problem.

### Limitations

1. The study was limited by the reliabilities of the methods employed and the limitations of the equipment used.
2. The study was limited by temperature and humidity, as these were not controlled.
3. No control was placed upon the activity of the subject on the day of the test.
4. The definition used for steady state limits the study.





5. As the sample was not completely random, the inferences from this study are limited.
6. The subjects in experiment one experienced some difficulty in maintaining a regular 50 rpm, thus limiting the study.

#### Delimitations

1. Forty-eight male students from the University of Alberta, Edmonton, were subjects for this investigation.
2. The ages of the subjects ranged from 19 to 30 years.
3. Only the parameters stated in the problem were considered.
4. Subjects were tested at the same time of the day for each trial.

#### Definitions of Terms

Kilopond. A kilopond is the force exerted by the gravitational attraction on a mass of one kilogram: that is, a force of one kilopond acting on a mass of one kilogram produces an acceleration of 9.81 meters/sec<sup>2</sup> (acceleration of gravity).

Kilopond Meter. (kpm) One kilopond meter is the unit of work performed by a force of one kilopond moving its point of application one meter in the direction of the force.

Physical Work Capacity. Physical work capacity is the individual's total ability to perform prolonged physical work: that is, the ability of the cardiopulmonary system to take up, transport, and give off oxygen to the muscle tissues for the performance of physical work (27).

Work Load. Work load refers to the rate of work. The unit of rate of work or power used in this investigation is the kilopond meter per minute (kpm/min).



Constant Work Load. Constant work load refers to work load that is independent of minor fluctuations in the rate of pedalling for the machine used.

Steady State. Steady state is a sign of economical working conditions, the reaction of the respiratory and circulatory systems being the most important factors in maintaining equilibrium between oxygen need and oxygen supply (34).

Steady State Heart Rate. For this investigation the steady state heart rate was taken as the average heart rate of the 5th and 6th minute of exercise, provided that they did not differ by more than  $\pm 5$  beats per minute.

Steady State Respiration Rate. For this investigation the steady state respiration rate was taken as the average respiration rate of the 5th and 6th minute of exercise.

Pre-exercise Heart Rate. Pre-exercise heart rate refers to the heart rate prior to the exercise performed on the bicycle ergometer.



## CHAPTER II

### REVIEW OF THE LITERATURE

#### History of the Electrodynamic Brake Ergometer

The earliest investigations in the use of an electric brake bicycle ergometer were made in 1903 by Atwater and Benedict (7), who simply pressed the drive wheel of a small dynamo to the rear wheel of a bicycle and measured the current generated. As there was considerable slip in the contact and uncertainty in the determination of the work performed, this method proved unreliable. Moreover, there was no possibility of varying the work load. Benedict and Carpenter (10), in 1909, and Benedict and Cady (9), in 1912 (cited in 32), employed an electric brake bicycle ergometer which was built by replacing the rear wheel of a bicycle with a copper disc. When the pedals were turned the disc rotated between the pole faces of an electro-magnet, providing a constant source of resistance. The resistance could be varied by changing the magnitude of the current flowing through the coils of the electromagnet. It is reported, by Tuttle and Wendler (32), that this ergometer was ". . . fairly accurate" and reliable when properly used, but was difficult to calibrate and did not provide a convenient method of recording data or work output.

In 1913, Krogh (22) developed an ergometer that replaced the rear wheel by a copper disc with a heavy lead ring acting as a fly wheel. This ergometer was capable of providing a resistance of 2900 kpm/min. which, according to Krogh, ". . . is probably more than any man can







perform for more than two minutes" (22:37).

In 1933, Kelso and Hellebrandt (19) designed a completely automatic, electrodynamic brake bicycle ergometer which employed a direct current generator as the brake. The armature of the generator was connected to the pedal sprocket of the bicycle and the pedalling motion rotated the armature. The field coils of the generator were independently excited by a 12-volt storage battery, producing a magnetic field in which the armature revolved. When the revolving armature was placed in an electric circuit, in this case a resistor and a recording voltmeter, a current flowed through it. This current set up a magnetic field of the field coils, thereby producing the braking action of the ergometer. The resistance could be accurately controlled by varying the flow of current in the field coils. Through careful calibration of the instrument it was possible to interpret the terminal voltage of the armature in terms of work rate.

The design of Kelso and Hellebrandt was improved upon in 1945 by Tuttle and Wendler (32). The new design was essentially the same, but was operated by alternating current. The current for exciting the field coils was obtained by means of a rectifier unit built into the circuit, thereby providing a reliable and convenient source of direct current. To provide rotary inertia for smooth pedalling, an eight inch flywheel, weighing fifteen pounds, was fastened to the drive shaft. Since the braking action of the generator varied directly with the flow of current through the field coils, it was possible to adjust the load to suit the muscular strength of the subject to meet experimental



requirements, and to assure accurate duplication of work loads.

#### Development of the Constant Work Load Ergometer

The ergometer used in this study was designed according to the plans of Holmgren and Mattsson (18). It was developed for elderly and cardiopulmonary patients because of difficulties they experienced in maintaining a set pedalling rate, as is necessary with a friction belt ergometer. The ergometer consists of a pedalling mechanism similar to that of an ordinary cycle, a separately magnetized direct current generator providing the resistance. The generator is governed by a regulator and recharges its effect to a loading resistance. Irregularity in the pedalling movement is reduced by means of a flywheel placed on the generator. The voltage of the generator is kept constant by feeding the difference in voltage between a reference voltage indicator and the generator voltage to an electronic amplifier which governs the current to the field winding of the generator. In this way the regulator strives to keep the difference between generator voltage and reference voltage at zero.

The accuracy of the ergometer is stated as  $\pm 5\%$  at all loads from 200-2000 kpm/min. It is stated that the effect is constant during the whole pedalling movement, even in cases of extreme degrees of irregular pedalling.

#### Current Use of the Constant Work Load Ergometer

There are many examples in the literature of the use made of constant work load ergometers, but in the main these are in the field of medicine and rehabilitation. Holmgren (17) and Sandberg (29) have made





extensive use of the ergometer in Sweden, while Cumming and Cumming (13) have used this type of ergometer in Canada. Cumming and Cumming state (13:353) that this ergometer ". . . allows an accurate setting of the resistance loads over a wide range of values, and also has the advantage of making the working load independent of minor fluctuations in the rate of pedalling."

#### Literature Associated with Parameters Measured

All out maximal work tests are dependent upon will-power and determination, which vary tremendously from subject to subject. The object of any work-test is to increase the oxygen requirement of the subject. The two most reliable measurements of cardiorespiratory function during a work-test are measurements of oxygen consumption and cardiac output (13). Because of the time consumed and patient discomfort of breathing into apparatus while exercising, oxygen consumption has not been used. Similarly, cardiac output measurements have not been employed in this study. Many investigators (2,4,6,13,14,25) have clearly indicated that there is a linear relationship between pulse rate and oxygen consumption during exercise. For this reason pulse rate was the main parameter measured during this investigation. Wahlund (34) and Sjöstrand (31) reported that pulse rate is as accurate an index of working capacity and physical fitness as other more complicated measurements of maximum oxygen intake and cardiac output. Glassford et al (16) found that the Astrand-Ryhming indirect test, which uses heart rates only, produced mean values equivalent to those obtained on direct treadmill tests of maximal oxygen consumption. The pulse rate test is based on the simple





fact that the well-trained individual is able to perform a given work load at a lower pulse rate than the untrained individual (13). Both the Sjöstrand Test (31) and the Astrand-Ryhming Predicted Test (3) determine values from steady state heart rate and are based on the demonstrated linear relationship between steady state heart rate and work load (4,11,13,30,34).

Wahlund (34) found that the respiratory rate shows a regular increase with work load but it appeared to be a less stable factor than pulse rate. In this present investigation respiratory rate was measured to help determine whether a steady state had been achieved during exercise.

#### Summary of the Review of Literature

This review has presented a history of the electrodynamic brake ergometer, tracing its development to the present constant work load ergometer, and outlining some studies that have been based upon it. Owing to the overwhelming evidence of the linear relationship between heart rate values between 120 and 170 beats per minute, and oxygen consumption during exercise, heart rate was the main parameter measured during this study.



## CHAPTER III

### METHODS AND PROCEDURES

#### Sample

Forty-eight healthy male subjects aged from 19 to 30 years participated in this study, the total sample being comprised of volunteer students from the University of Alberta, Edmonton. Trials for each subject were conducted on separate days, each test being at the same time of day. Subjects were randomly allocated to groups by use of a table of random numbers (20), and to overcome any improvement from trial to trial, they were allocated to trials in different experimental order.

#### Experimental Groups

The investigation consisted of four experiments. The first experiment studied different pedalling speeds with a group of twelve subjects. Each subject pedalled for six minutes at 1000 kpm/min., on different days at 50 rpm, 70 rpm, and a varying rate from 50 to 70 rpm. A work load of 1000 kpm/min. was chosen, as a pilot study had indicated that this work load would achieve an approximate mean heart rate of from 150-160 beats per minute for the group studied. Subjects were deleted from the study if the heart rate response for any trial was greater than 170 beats per minute. The experimental condition where the pedalling rate was varied was completed as follows: the subject commenced the test by pedalling at 50 rpm for 20 seconds; at the end of 20 seconds, the subject was allowed 5 seconds to increase the pedalling rate from 50 rpm to 70 rpm; the increased rate of 70 rpm was maintained for 20 seconds and then the





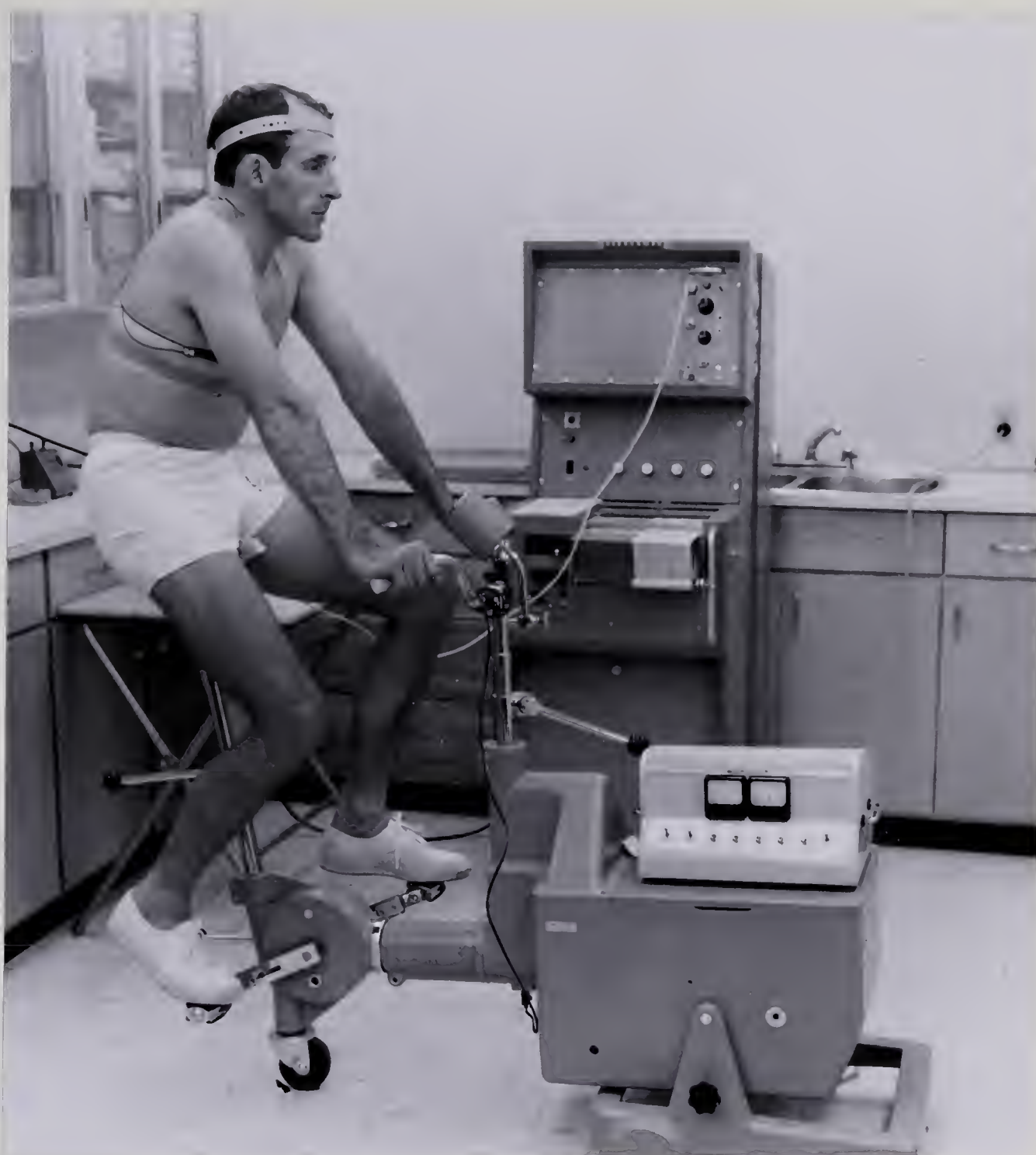


FIGURE 1

THE ELEMA SCHONANDER CONSTANT WORK LOAD BICYCLE ERGOMETER  
WITH THE SANBORN FOUR CHANNEL RECORDER  
IN THE BACKGROUND





subject was allowed 5 seconds to decrease from 70 rpm to 50 rpm. This routine was repeated throughout the six minutes of the exercise.

The second section of the study investigated varying pedal arm lengths. A group of twelve subjects was tested on two occasions, once with the pedalling arms short, and once with the pedalling arms long. The duration of the exercise was six minutes and the work load was 1000 kpm/min.

The third experiment was designed to determine whether there is any significant difference between the measured physiological responses of two work loads selected from the limits of the prescribed reliability ( $\pm 5\%$ ) for 1000 kpm/min. In this section of the investigation twelve subjects were tested three times, once at 950 kpm/min., once at 1000 kpm/min., and once at 1050 kpm/min. The duration of each test was six minutes, with a pedalling rate of 60 rpm.

The fourth experiment involved reliability. A group of twelve subjects was tested on two occasions at 1000 kpm/min. at 60 rpm for six minutes.

#### Summary of Experimental Groups (Total 48 subjects)

Experiment 1 Varying pedalling rates. (12 subjects)

6 minutes exercise at a work load of 1000 kpm/min.

a) 50 rpm

b) 70 rpm

c) Varying rate (from 50 to 70 rpm)

Experiment 2 Varying pedal positions. (12 subjects)

6 minutes exercise at a work load of 1000 kpm/min. (60 rpm)



a) Pedals short

b) Pedals long

Experiment 3 Effect of 1000 kpm/min. difference. (12 subjects)

6 minutes exercise at 60 rpm

a) 950 kpm/min.

b) 1000 kpm/min.

c) 1050 kpm/min.

Experiment 4 Reliability.(12 subjects)

a) 1000 kpm/min. at 60rpm for 6 minutes

b) 1000 kpm/min. at 60rpm for 6 minutes

#### Parameters and Equipment

The parameters of respiration rate and heart rate were recorded on a Sanborn Four Channel Recorder (model 964). Respiration rate was measured by means of a Sanborn Pneumograph Attachment (model 108) and a Sanborn Pulse Wave Attachment (model 374), while heart rate was recorded from two chest electrodes and a reference electrode fitted to the subject's forehead. (See Figure 1.)

#### Conditions of Testing

All tests were carried out in the Fitness Research Unit Laboratories at the University of Alberta. Temperature, although uncontrolled, was  $24 \pm 2^{\circ}$  centigrade during the tests. Relative humidity was not controlled. All subjects were tested at the same time of day, and wore similar clothing during each trial in an attempt to control as many external variables as possible.





Subjects were brought into the laboratory prior to the testing time, so that age, height, and weight could be recorded. Laboratory temperature was recorded at this time also. Subjects were fitted with the pneumograph and electrocardiograph leads in preparation for the test, and during this time were informed of the procedure required to complete the test. The height of the bicycle seat was adjusted so that when the subject had a foot in the lower position, the instep could just reach the pedal. The handlebars were adjusted to each subject's liking.

In the second experiment, where the group was tested with varying pedal arm lengths, the height of the seat was adjusted for each subject so that the foot was placed in the same position on the pedal and the angle at the knee was kept constant for each trial. Prior to the actual exercise, the subject rested quietly for five minutes, seated on the ergometer.

#### Testing Procedure

1. A five minute rest period preceded each test.
2. The heart rates and respiration rates were recorded continuously as follows:
  - 2 minutes prior to exercise
  - during the 6 minutes of exercise
  - for 5 minutes of recovery after the exercise.
3. The steady state heart rate was taken as the average of the 5th and 6th minute of exercise provided these values did not exceed  $\pm 5$  beats per minute (5).
4. During each test the subject maintained a pedalling rate specific





for that portion of the investigation. The subject maintained the required pedalling rate by observation of the speedometer attached to the ergometer. This rate was frequently checked by the investigator.

5. To ensure that the ergometer was functioning according to the specifications of the manufacturer, the voltmeter and the amperemeter were checked frequently (see Appendix C).

### Statistical Analysis

Null Hypotheses. Within each experimental group the null hypothesis states that there is no significant difference between the means of each experimental treatment at the .05 level. Thus the null hypotheses are:

Experiment 1      $H_0: \mu_1 = \mu_2 = \mu_3$

Experiment 2      $H_0: \mu_1 = \mu_2$

Experiment 3      $H_0: \mu_1 = \mu_2 = \mu_3$

Experiment 4      $H_0: \mu_1 = \mu_2$

Allocation of Subjects to Groups. It was considered unnecessary to use a randomly selected sample for this investigation as it is a study designed to test the accuracy of the constant work load ergometer, rather than a study of a sample group to make inferences concerning a particular population. Each subject was randomly allocated to an experimental group (refer Appendix A). The subjects were equally allocated to groups in different experimental order so that results would in no way be affected by repeated performances on the ergometer. In this way it was hoped that the effect of learning, or improvement from performance to performance, would be overcome.



Treatment of Results. The computer at the University of Alberta was used (Program G2011) to calculate the means, variances, standard deviations, sums of squares and cross products, and Pearson's product-moment correlation coefficients of all variables within each experiment. Computer Program BMD02V was used to compute an analysis of variance to test the significance of the differences between the means of each experimental condition within each experiment. A t test could have been used in experiment two and experiment four where there were only two variables, and so only two means ( $k = 2$ ), but for consistency the analysis of variance technique was used for each experiment.

Briefly, to test the significance of the differences between  $k$  means using the analysis of variance, the following steps are involved (15:235):

1. Partition the total sum of squares into two components, a within-groups and a between-groups sum of squares, using the appropriate computation formulas.
2. Divide these sums of squares by the associated number of degrees of freedom to obtain  $s_w^2$  and  $s_b^2$ , the within-and -between groups variance estimates.
3. Calculate the F ratio  $s_b^2/s_w^2$  and refer this to the table of F (15:310).
4. If the probability of obtaining the observed F value is small, less than .05 as stated under the null hypothesis, reject that hypothesis.

Assumptions of the Analysis of Variance. A number of assumptions (15:239) are made in the mathematical development of the analysis of





variance:

1. That the distributions of the variables in the populations from which the samples are drawn are normal.
2. That the variances in the populations from which the samples are drawn are equal. (Homogeneity of variance.)
3. That the various factors on the total variation are additive, as distinct from multiplicative.

One advantage of the analysis of variance is that reasonable departures from the assumptions of normality and homogeneity may occur without seriously affecting the validity of the inferences drawn from the data (15:240).

Comparison of Means. The Newman-Keuls method (35:80) of probing the nature of the differences between treatment means was used if a significant over-all  $F$  was found for any experimental condition. This method was chosen over less conservative tests such as Duncan's (35:85), because of the smaller probability of a type I error. It was hoped, therefore, that more confidence would be placed in any declared significant results. One disadvantage of the Newman-Keuls test is the higher probability of a type II error, that is, a failure to reject a null hypothesis when false. Such tests as Tukey's (35:87), which are more conservative than Newman-Keuls were not chosen as it was felt that they are too conservative for this type of study. The difference between Duncan's and Newman-Keuls' tests is only evident for the experimental groups with three variables; for two groups they are equivalent methods. Another reason for choosing a moderately conservative test is that there





is no prior research to indicate any trend of the form which the results may take.

Significance of a Correlation Coefficient (15:152). In experiments one, two, and three the correlation coefficients obtained for each pair of variables were examined to determine if the correlation coefficients were significant. As the number of degrees of freedom ( $df = 10$ ) was comparatively small for this type of  $t$  test, a high level of significance has been chosen (.005) to determine the significance of the correlation coefficients. Therefore, a correlation equal to, or greater than .708 will be required for significance (15:315).

A detailed description of the statistical technique used in this investigation is given in Appendix B.



## CHAPTER IV

### RESULTS AND DISCUSSION

#### Age, Weight, and Height of Subjects

Table I gives the means, variances, and standard deviations of age, weight, and height for each group of subjects used in each experiment.

TABLE I

MEAN, VARIANCE, AND STANDARD DEVIATION  
OF AGE, WEIGHT, AND HEIGHT  
FOR EACH EXPERIMENT

		MEAN	VARIANCE	STANDARD DEVIATION
EXPERIMENT	AGE	22	8.33	2.89
1				
(Varying	Wt. (lb.)	165	119.24	10.92
pedalling				
rates)	Ht. (in.)	69	22.78	1.51
EXPERIMENT	AGE	23	20.63	4.54
2				
(Varying	Wt. (lb.)	172	319.97	17.89
pedal arm				
lengths)	Ht. (in.)	70	46.12	2.15
EXPERIMENT	AGE	25	21.30	4.61
3				
(Varying	Wt. (lb.)	178	290.08	17.03
work				
loads)	Ht. (in.)	71	49.09	2.22
EXPERIMENT	AGE	22	4.62	2.15
4				
(Reliability)	Wt. (lb.)	175	200.20	14.15
	Ht. (in.)	71	30.83	1.76





### Results of Experiment One - Varying Pedalling Rates

The means obtained from the experimental methods used in experiment one are given in Table II. The means for pre-exercise heart rate, steady state heart rate, recovery heart rate (0-1 minutes), recovery heart rate (4-5 minutes), and steady state respiration rate are indicated according to their experimental treatments. The F value obtained from an analysis of variance for each group of means is also indicated in the table. (For analysis of variance calculations see Appendix F.)

TABLE II  
EXPERIMENT 1  
VARYING PEDALLING RATES  
( $\alpha = .05$  df 2,22)

MEANS AND F VALUES					
Treatment	Pre-exercise Heart Rate	Steady State Heart Rate	Recovery Heart Rate (0-1 min.)	Recovery Heart Rate (4-5 min.)	Steady State Respiration Rate (breaths/min.)
50	76.7	149.4	119.0	96.1	31.4
70	75.5	157.8	121.7	94.7	33.1
V	76.3	154.8	122.3	94.8	30.9
F		6.40*	.43	.24	3.83*

\* Significant at the .05 level

The F values for pre-exercise heart rate, recovery heart rate (0-1 min.), and recovery heart rate (4-5 min.) are below the significant level selected for this investigation (refer Appendix F). On the other









Table IV gives the results of a Newman-Keuls Test which was applied to the means of the steady state respiration rates.

TABLE IV

NEWMAN-KEULS TEST FOR SIGNIFICANCE OF DIFFERENCES  
BETWEEN PAIRS OF INDIVIDUAL MEANS

STEADY STATE RESPIRATION RATE				
Treatment means in order				
	70	50	V	
	30.9	31.4	33.1	
70	30.9	-	.5	2.2*
50	31.4			1.7





difference between the steady state respiration rate means of the 70 rpm treatment and the 50 rpm treatment is of interest. In the heart rate response this difference was well beyond the significance required (8.33 obtained, 5.93 required).

#### Discussion of Varying Pedalling Rate Results

This investigation was somewhat restricted because of the necessity of relying upon the calibration technique carried out by the company that constructed the ergometer. In the test report issued with the machine the differences among the nominal work loads and the measured work loads are given (see Appendix C). For a nominal work load of 1000 kpm/min. the measured work loads at varying pedalling rates were 45 rpm = 1000 kpm/min., 60 rpm = 1000 kpm/min., and 75 rpm = 1012 kpm/min.

During the investigation the voltmeter reading was 87 volts, and when a work load of 1000 kpm/min. was employed the amperemeter reading was 1.34 amps, indicating that the ergometer was functioning according to the specifications.

The results of experiment one indicate that although the different pedalling rates may maintain a constant work load, in this study 1000 kpm/min., the effect upon the measured physiological mechanisms is not constant. As reported previously, the Astrand-Ryhming Nomogram (3), and the Sjöstrand Physical Work Capacity Test (31), as well as being based on the linearity of heart rate with oxygen intake, depend upon the linear relationship between heart rate and work load. This linearity of heart rate and work load is supported by other



investigators (11,13,30,34). However, it becomes apparent from the results of this investigation that, in addition to work load, there is another factor influencing heart rate response to exercise; this factor may be related to velocity of movement.

When relating these results to the practical use of the ergometer, one must be cautious as the results of the experiment show that the methods of this investigation have limited inferences. Steady state heart rate means, as presented in Table II, for 50 rpm and 70 rpm are approximately eight beats per minute apart (149 to 158 beats per minute), while the steady state heart rate mean for the varying rate lies approximately at the mid-point between these values (154 beats per minute). It is probable that if a fourth treatment of pedalling at 60 rpm had been included, the mean steady state heart rate for 60 rpm may have been located near the mid-point between the means for 50 rpm and 70 rpm. This possibility is very likely as the steady state heart rate means obtained for both experiment two and experiment four, where subjects pedalled at 60 rpm at 1000 kpm/min., do lie around the mid-point value (refer Table V and Table VIII). However, the comparison of means from one group of subjects to another was not intended in this study.

If the above possibility were verified, one could conclude that the mean heart rate and respiration rate responses while pedalling at 60 rpm do not differ from pedalling at varying rates from 50 rpm to 70 rpm, even though pedalling at 50 rpm and pedalling at 70 rpm do differ from each other. However, a treatment of pedalling at 60 rpm was not included in experiment one. Therefore, as the results stand







there are significant differences in heart rate responses and respiration rate responses when the pedalling rate is varied.

Results of Experiment Two - Varying Pedal Arm Lengths

Table V below summarizes the results of experiment two and shows the means and F values for pre-exercise heart rate, steady state heart rate, recovery heart rate (0-1 min.), recovery heart rate (4-5 min.), and steady state respiration rate for the varying pedal arm length treatments. The length of each pedalling arm in the long position was seven inches and in the short position was five inches, making a total variation of four inches in the diameter of the pedalling arms.

TABLE V  
EXPERIMENT 2  
VARYING PEDALLING ARM LENGTHS  
( $\alpha = .05$  df 1,11)

MEANS AND F VALUES					
Treatment	Pre-exercise Heart Rate	Steady State Heart Rate	Recovery Heart Rate (0-1 min.)	Recovery Heart Rate (4-5 min.)	Steady State Respiration Rate (breaths/min.)
LONG	89.6	157.9	122.3	100.6	26.7
SHORT	86.7	157.2	121.3	99.6	26.9
F		.26	.10	.13	.08

The F values given above in Table V indicate that there is no significant difference between the means of the heart rate response or the respiration rate response for the treatment conditions. These



results indicate that there is no difference in the means obtained when the pedalling arm lengths are varied. Hence, the null hypothesis as stated for experiment two, that  $\mu_1 = \mu_2$ , should not be rejected.

### Results of Experiment Three - Varying Work Loads

Table VI below presents the means and F values for pre-exercise heart rate, recovery heart rate (0-1 min.), recovery heart rate (4-5 min.), and steady state respiration rate for the varying work load treatments of experiment three.

TABLE VI  
EXPERIMENT 3  
VARYING WORK LOADS

MEANS AND F VALUES					
Treatment	Pre-exercise Heart Rate	Steady State Heart Rate	Recovery Heart Rate (0-1 min.)(4-5 min.)	Steady State Respiration Rate (breaths/min.)	
950	85.2	146.5	116.8	97.2	28.9
1000	80.8	149.0	117.4	95.8	27.2
1050	78.0	151.6	120.5	95.4	29.3
F		3.43	.90	.19	1.60

Inspection of the analysis of variance results shows that the F values are all below that required for significance at the .05 level ( $F_{(2,22)} = 3.44$ ). However, because a value of 3.43, as obtained for an analysis of variance of the means for steady state heart rate, approaches





significance at the .05 level, it was felt that a Newman-Keuls Test of a comparison of pairs of individual means might reveal significance not evident from the overall analysis of variance. This test involves a posteriori comparisons and is discussed by Winer (35:208).

Table VII presents the results of a Newman-Keuls Test of the comparisons of pairs of individual means of the steady state heart rates of experiment three.

TABLE VII  
EXPERIMENT 3  
NEWMAN-KEULS TEST FOR SIGNIFICANCE OF DIFFERENCES  
BETWEEN PAIRS OF INDIVIDUAL MEANS

STEADY STATE HEART RATE				
Treatment means in order				
<hr/>				
<hr/>				
	950		1000	1050
	<hr/>		<hr/>	<hr/>
	146.5		149.0	151.6
	<hr/>		<hr/>	<hr/>
950	146.5	-	2.5	5.1*
1000	149.0		-	2.6
	<hr/>		<hr/>	<hr/>

\* Significant at .05 level

From Table VII above it is evident that the mean obtained for exercise at 950 kpm/min. is significantly different at the .05 level from the mean obtained for exercise at 1050 kpm/min. It is also evident in Table VII that neither exercise at 950 kpm/min, nor exercise at 1050 kpm/min. differs significantly at the .05 level from exercise at 1000 kpm/min. However, as there is a significant difference between the means of the experimental treatments, 950 kpm/min. and





1050 kpm/min., the null hypothesis for steady state heart rate, that  $\mu_1 = \mu_2 = \mu_3$  as stated for experiment three, should be rejected.

#### Discussion of Varying Work Load Results

Although the results of experiment three reject the null hypothesis, that  $\mu_1 = \mu_2 = \mu_3$ , this section of the investigation was aimed more at determining the effect of 100 kpm/min. difference about a work load of 1000 kpm/min., that is, the effect of two work loads that are  $\pm 5\%$  of a third work load as prescribed in the accuracy of the machine. These results indicate that the ergometer is sensitive enough to distinguish a 100 kpm/min. difference, but not sensitive enough to distinguish a 50 kpm/min. difference.

When the results of experiment three are compared with the results of experiment one, it is interesting to note that a significant difference of approximately five heart beats per minute occurred among the means of the different work loads investigated, while a significant difference of approximately eight heart beats per minute occurred among the means of the different pedalling rates investigated. This result implies that less error would occur when pedalling rate is held constant, as occurs when exercising on the friction brake bicycle ergometer, rather than when the pedalling rate is varied, as could occur when exercising on the constant work load ergometer.

#### Results of Experiment Four - Reliability

Analysis of Variance. The means and F values for trials one and two of experiment four are shown in Table VIII.



TABLE VIII

## EXPERIMENT 4

RELIABILITY  
( $\alpha = .05$  df 1,11)

MEANS AND F VALUES					
Treatment	Pre-exercise Heart Rate	Steady State Heart Rate	Recovery Heart Rate (0-1 min.)	Heart (4-5 min.)	Steady State Respiration Rate (breaths/min.)
TEST 1	86.3	156.9	123.6	101.4	29.4
TEST 2	80.5	153.3	118.0	97.3	27.9
F		4.08	2.04	2.56	8.49*

\* Significant at .05 level

The F values for pre-exercise heart rate, steady state heart rate, recovery heart rate (0-1 min.), and recovery heart rate (4-5 min.) are below the value required for significance at the .05 level.

( $F(1,11) = 4.84$ ). Thus, for the results of steady state heart rate, the null hypothesis for experiment four, that  $\mu_1 = \mu_2$ , should not be rejected. The F value of 8.49 obtained from an analysis of variance of the means for steady state respiration rate indicates a significant difference between the means of trial one and trial two. Thus, for steady state respiration rate, the null hypothesis for experiment four, that  $\mu_1 = \mu_2$ , should be rejected.

Reliability. Table IX presents the reliabilities obtained from experiment four between the test, retest conditions.





TABLE IX  
EXPERIMENT 4  
RELIABILITY COEFFICIENTS

Reliability	Pre-exercise Heart Rate	Steady State Heart Rate	Recovery Heart Rate (0-1 min.)	Steady State Respiration Rate (breaths/min.)
$r(T_1, T_2)$	.61	.85	.67	.73

Correlation Coefficients

Table X presents the correlation coefficients obtained from the exercise variables in experiments one, two, and three.

TABLE X  
EXPERIMENTS ONE, TWO, AND THREE

CORRELATION COEFFICIENTS  
( $r_{.005} = .708$  df 10)

Experiment	Treatment r	Steady State Heart Rate	Recovery Heart Rate (0-1 min.)	Steady State Respiration Rate (breaths/min.)
1	$r(50, 70)$	.83*	.82*	.83*
	$r(50, V)$	.73*	.71*	.78*
	$r(70, V)$	.87*	.76*	.80*
2	$r(L, S)$	.81*	.58	.29
3	$r(1, 2)$	.73*	.84*	.73*
	$r(1, 3)$	.88*	.85*	.66
	$r(2, 3)$	.76*	.82*	.68

\* Significant at .005 level



An analysis of the results shown in Table X reveals that every correlation coefficient in experiment one is significantly different from zero at the .005 level. In experiments two and three the correlation coefficients for steady state heart rate and steady state respiration rate are significantly different from zero at the .005 level.



## CHAPTER V

### SUMMARY AND CONCLUSIONS

#### Summary

This study investigated the reliability and accuracy of the Elema-Schölander constant work load bicycle ergometer, which is built according to the design of Holmgren and Mattsson (18), and is considered to maintain a constant work load ( $\pm 5\%$ ), provided the pedalling frequency is between 45 rpm and 75 rpm, regardless of whether a constant pedalling rate is maintained. The main problem was to determine whether the physiological responses of heart rate and respiration rate are constant regardless of pedalling rate. Subsidiary problems investigated the effect on these parameters of varying pedalling arm lengths, varying work loads within the prescribed accuracy of the ergometer, and the reliability of the ergometer to two test performances at a constant pedalling rate.

The study was divided into four experiments, each experiment using twelve subjects to investigate one of the problems mentioned above. The first experiment investigated the heart rate and respiration rate responses to pedalling rates of 50 rpm, 70 rpm, and a varying rate from 50 rpm to 70 rpm at a work load of 1000 kpm/min. An analysis of the results of this experiment reveals that there is a significant difference in heart rate responses and in respiration rate responses when a subject exercises on the ergometer at different pedalling rates.

Experiment two investigated the effect upon the physiological





responses of heart rate and respiration rate of a short pedalling arm length and a long pedalling arm length at a work load of 1000 kpm/min. As there was no significant difference between the steady state heart rates, or between the steady state respiration rates, it may be concluded that changing pedalling arm lengths within the possible adjustment limits of the machine does not affect the measured physiological responses.

The third experiment investigated the difference between the measured physiological responses of two work loads selected from the prescribed accuracy ( $\pm 5\%$ ) of the ergometer for 1000 kpm/min. The results showed a difference in the steady state heart rate responses of 950 kpm/min. and 1050 kpm/min., although there were no significant differences between 950 kpm/min. and 1000 kpm/min., or between 1000 kpm/min. and 1050 kpm/min.

Experiment four investigated the reliability of two test trials at 60 rpm at a work load of 1000 kpm/min. There was no significant difference in the steady state heart rate responses of the two trials, but there was a significant difference in the steady state respiration rate responses of the two trials. The reliability coefficient of the steady state heart rate of two trials was .85, while the reliability coefficient of the steady state respiration rate of two trials was .91, indicating that the ergometer is reliable under the conditions of this experiment.

### Conclusions

Within the limits of the sample tested and the reliabilities of



the experimental procedures employed, the following conclusions appear justified:

1. Exercise at different pedalling rates within the prescribed accuracy of the ergometer elicits different steady state heart rate and steady state respiration rate responses.
2. Changing the pedalling arm lengths within the limits of the present adjustment of the ergometer does not affect the steady state heart rate or the steady state respiration rate responses to submaximal exercise.
3. The ergometer is sensitive enough to distinguish a 100 kpm/min. difference, but not sensitive enough to distinguish a 50 kpm/min. difference at a work load of 1000 kpm/min.
4. The ergometer provides reliable results to exercise tests when pedalled at a constant rate.

#### Recommendations

1. Experiment one would have been improved if a fourth treatment of pedalling at 60 rpm had been included. Such a change would have enabled a comparison to be made between 60 rpm and a varying rate of pedalling.
2. The reliability obtained in experiment four may have been improved if the subjects had been given a preliminary test to familiarize themselves with the ergometer in a test situation.
3. The first conclusion involving pedalling rate may stem from a factor associated with velocity of movement and heart rate, rather than from the accuracy of the Elema-Schölander constant work load





bicycle ergometer. This factor may affect the concept of linearity of heart rate and work load and should be investigated. Such an investigation could be carried out on a friction brake bicycle ergometer by varying the position of the pendulum that determines the work load, so that a constant work load may result for different rates of pedalling.



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## REFERENCES

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## APPENDIX A

### ALLOCATION OF SUBJECTS TO GROUPS



ALLOCATION OF SUBJECTS TO GROUPS  
AND TREATMENT ORDERS

EXPERIMENT 1		EXPERIMENT 2		EXPERIMENT 3		EXPERIMENT 4	
Varying Pedalling Rates		Varying Pedalling Arm Lengths		Varying Work Loads		Reliability	
1	10 (70,V,50)	13	41 (L,S)	25	32 (950,1000,1050)	37	7
2	44 (V,70,50)	14	33 (L,S)	26	4 (1050,950,1000)	38	14
3	35 (70,50,V)	15	43 (L,S)	27	18 (950,1000,1050)	39	48
4	2 (50,70,V)	16	45 (S,L)	28	36 (1050,1000,950)	40	19
5	24 (V,70,50)	17	1 (L,S)	29	28 (950,1050,1000)	41	30
6	17 (70,V,50)	18	31 (S,L)	30	46 (1000,1050,950)	42	8
7	29 (50,70,V)	19	27 (L,S)	31	3 (950,1050,1000)	43	20
8	15 (50,V,70)	20	42 (S,L)	32	11 (1050,1000,950)	44	12
9	38 (V,50,70)	21	39 (S,L)	33	22 (1000,950,1050)	45	21
10	6 (70,50,V)	22	23 (S,L)	34	40 (1000,950,1050)	46	47
11	13 (V,50,70)	23	5 (S,L)	35	37 (1050,950,1000)	47	34
12	9 (50,V,70)	24	16 (L.S)	36	25 (1000,1050,950)	48	26

Explanation. Subjects were allocated to groups and treatment orders using the following method: a location on a page of a Table of Random Numbers (20) was selected by chance; each subject was allocated to a position corresponding to the subject numbers 1 to 48. For example, as number 17 appeared first in the table, the first subject was allocated to experiment two in position 17, the second subject to experiment one, position 4. This allocation was continued until all subjects had been allocated.





## APPENDIX B

### STATISTICAL TECHNIQUES



## STATISTICAL TECHNIQUES

Computation of the Mean (15:37) $\bar{X}$  = mean

$$\bar{X} = \frac{\sum x}{N}$$

 $\sum x$  = the sum of the values for each value of x

N = number of scores.

Computation of the Standard Deviation and Variance (15:56)

s = standard deviation

$$s = \sqrt{\frac{\sum X^2}{N} - \bar{X}^2}$$

 $s^2$  = variance $\sum X^2$  = the sum of the values of x squared

$$s^2 = \frac{\sum X^2}{N} - \bar{X}^2$$

N = number of scores.

Computation of the Correlation Coefficients (15:92)

r = correlation coefficient

$$r = \frac{N\sum XY - \sum X\sum Y}{\sqrt{[N\sum X^2 - (\sum X)^2][N\sum Y^2 - (\sum Y)^2]}}$$

N = number of paired observations

 $\sum X$  = the sum of the values for each observation of x $\sum Y$  = the sum of the values for each observation of yComputation of the Analysis of Variance (15:236)

## A. Sums of Squares

$$1. \text{ Total Sum of Squares (SS}_T) = \sum_{j=1}^k \sum_{i=1}^{n_j} X_{ij}^2 - \frac{T^2}{N}$$

$$2. \text{ Within-Groups Sum of Squares (SS}_W) = \sum_{j=1}^k \sum_{i=1}^{n_j} X_{ij}^2 - \sum_{j=1}^k \left( \frac{T_j^2}{n_j} \right)$$

$$3. \text{ Between-Groups Sum of Squares (SS}_b) = \sum_{j=1}^k \left( \frac{T_j^2}{n_j} \right) - \frac{T^2}{N}$$

$$4. \text{ Interaction Sum of Squares} = SS_T - SS_W - SS_b$$

(Where T = sum of all observations in k groups,

and  $T_j^2/n_j$  = square of the sum of the jth group divided by the number of cases.)





## B. Analysis of Variance

Source of Variation	df	Sum of Squares	Mean Square	F
Between groups	k-1	SS <sub>b</sub>	SS <sub>b</sub> /k-1	MS <sub>b</sub> /MS <sub>Int.</sub>
Within groups	N-k	SS <sub>w</sub>	SS <sub>w</sub> /N-k	
Interaction	kN-k	Int.SS	Int.SS/kN-k	

Critical F ratios from Tables (15:310)

Newman-Keuls Test for Significance Between Pairs of Means (35:80)

$$q_r = \sqrt{MS_{\text{error}} / \tilde{n}}$$

r = number of steps two means are  
apart on an ordered scale

MS = mean square or variance of the  
interaction term

Truncated range r       $r = j_1 - j_2 + 1$

$q_r (.05)$  Obtained from tables (35:648)

Critical difference =  $q_{.05}(r, df) \sqrt{\tilde{n} MS_{\text{error}}}$

Significance of a Correlation Coefficient (15:152)

$$t = r \sqrt{\frac{N-2}{1-r^2}}$$

t = distribution of t

r = correlation coefficient

df = N - 2

Tables for above t test values (15:315).



APPENDIX C

CALIBRATION REPORT



TABLE XII

## TEST REPORT OF THE CALIBRATION OF THE ERGOMETER

Voltmeter reading: 87 volts

Nominal Work Load kpm/min	Amperemeter Reading A	Measured Work Load		
		45 rev/min	60 rev/min	75 rev/min
50	0.08	59	68	67
100	0.16	107	117	110
200	0.32	200	200	200
300	0.46	303	300	300
400	0.59	400	400	400
500	0.73	500	490	500
600	0.86	592	588	600
700	0.98	688	681	700
800	1.10	792	774	800
900	1.22	900	872	900
1000	1.34	1000	1000	1012
1200	1.56	1200	1176	1226
1400	1.76	1400	1382	1415
1600	1.95	1580	1568	1600
1800	2.10		1764	1800
2000	2.27		1950	1976
2050	2.30		2000	2031





APPENDIX D

INDIVIDUAL SCORE SHEET



# INDIVIDUAL SCORE SHEET

NAME \_\_\_\_\_ TELEPHONE \_\_\_\_\_ ADDRESS \_\_\_\_\_

AGE \_\_\_\_\_ Wt. \_\_\_\_\_ Ht. \_\_\_\_\_ SEAT HEIGHT \_\_\_\_\_ HANDLE HEIGHT \_\_\_\_\_

EXPERIMENTAL GROUP \_\_\_\_\_ EXPERIMENTAL ORDER \_\_\_\_\_

TIME	Date _____ Temp. _____		Date _____ Temp. _____		Date _____ Temp. _____	
	Heart rate	Respiration rate	Heart rate	Respiration rate	Heart rate	Respiration rate
Pre-exercise -2 to -1						
-1 to 0						
Exercise 1						
2						
3						
4						
5						
6						
Recovery 0 - 1						
4 - 5						

Steady state  
heart rate \_\_\_\_\_





APPENDIX E

RAW SCORES



TABLE XIII

## RAW SCORES - EXPERIMENT 1

Subject	Age	Wt. (lb.)	Ht. (in.)	HEART RATE					
				PRE-EXERCISE			STEADY STATE		
				50	70	V	50	70	V
1	26	152	70.5	87	84	89	159	160	153
2	23	159	68.5	97	85	89	170	169	165
3	21	172	72.0	57	59	54	141	150	138
4	24	174	68.5	73	80	76	133	154	145
5	19	164	69.0	66	70	82	148	160	169
6	20	162	70.0	92	87	98	161	162	164
7	20	150	67.0	70	68	64	159	168	167
8	28	159	70.0	71	70	58	131	141	124
9	20	165	70.0	73	76	66	157	155	158
10	20	180	71.0	78	70	81	145	156	153
11	19	185	69.0	90	95	97	154	170	169
12	22	156	67.0	66	62	62	135	148	153

Subject	HEART RATE						RESPIRATION RATE		
	RECOVERY (0-1)			RECOVERY (4-5)			STEADY STATE		
	50	70	V	50	70	V	50	70	V
1	136	130	130	109	103	107	250	245	215
2	146	141	146	113	109	107	330	320	295
3	104	114	93	86	87	74	285	360	305
4	100	115	110	87	97	92	255	305	265
5	90	111	128	86	88	100	455	490	450
6	141	140	145	111	105	108	220	240	250
7	126	122	122	94	92	83	385	355	360
8	100	105	78	84	83	70	265	255	275
9	128	118	125	94	89	93	400	405	365
10	122	128	130	98	95	102	320	355	340
11	128	140	145	103	112	115	340	355	290
12	107	96	116	88	76	86	260	285	295

(Note: Steady State Respiration Rate raw scores have been multiplied by ten to satisfy computer requirements.)



TABLE XIV

## RAW SCORES - EXPERIMENT 2

Subject	Age	Wt. (lb.)	Ht. (in.)	HEART RATE			
				PRE-EXERCISE		STEADY STATE	
				Long	Short	Long	Short
13	26	198	74.0	89	75	154	154
14	24	157	68.0	83	81	147	151
15	24	198	74.0	108	90	169	161
16	23	196	70.0	101	93	160	153
17	30	174	72.0	71	71	144	149
18	19	173	70.5	105	106	162	158
19	23	170	68.5	71	89	150	159
20	19	149	69.5	84	83	167	165
21	20	169	69.0	92	93	166	167
22	24	144	68.5	91	90	167	166
23	22	172	72.5	80	78	151	151
24	21	166	69.0	100	91	158	152

Subject	HEART RATE				RESPIRATION RATE	
	RECOVERY (0-1)		RECOVERY (4-5)		STEADY STATE	
	Long	Short	Long	Short	Long	Short
13	133	120	102	90	175	150
14	122	122	100	100	345	385
15	135	132	109	92	255	265
16	136	136	116	107	240	285
17	113	115	88	92	260	255
18	118	126	103	106	300	300
19	102	122	94	105	270	275
20	130	129	95	98	380	370
21	126	138	100	115	270	295
22	119	103	104	107	200	165
23	102	98	96	88	250	220
24	133	115	100	95	260	265

(Note: Steady State Respiration Rate raw scores have been multiplied by ten to satisfy computer requirements.)





TABLE XV

## RAW SCORES - EXPERIMENT 3

Subject	Age	Wt.	Ht.	HEART RATE					
				PRE-EXERCISE			STEADY STATE		
		(lb.)	(in.)	950	1000	1050	950	1000	1050
25	25	185	73.5	92	96	89	154	163	160
26	22	156	68.5	93	93	78	154	161	156
27	21	174	71.0	92	73	83	144	144	146
28	18	161	73.0	92	74	90	169	151	161
29	25	175	71.0	86	84	73	149	160	155
30	24	172	69.0	62	57	63	135	134	146
31	30	194	73.0	88	93	87	142	150	154
32	29	198	71.0	88	98	94	152	155	156
33	30	205	71.0	73	63	70	127	132	137
34	24	192	73.0	99	88	79	150	151	156
35	22	178	71.5	80	84	71	134	142	135
36	27	151	66.0	78	67	59	148	145	157

Subject	HEART RATE						RESPIRATION RATE		
	RECOVERY (0-1)			RECOVERY (4-5)			STEADY STATE		
	950	1000	1050	950	1000	1050	950	1000	1050
25	140	143	140	105	111	109	420	460	470
26	128	132	133	104	108	103	370	335	370
27	107	95	103	87	78	88	475	300	370
28	133	118	136	110	92	106	160	165	175
29	129	133	124	101	109	99	325	275	310
30	98	104	111	80	76	82	210	190	240
31	107	124	125	102	108	102	290	280	275
32	130	140	130	100	109	99	200	180	200
33	84	84	98	84	83	98	130	170	180
34	122	132	129	102	102	102	345	335	310
35	105	102	92	98	105	82	235	235	285
36	119	102	125	93	69	75	310	335	335

(Note: Steady State Respiration Rate raw scores have been multiplied by ten to satisfy computer requirements.)



TABLE XVI

## RAW SCORES - EXPERIMENT 4

Subject	Age	Wt. (lb.)	Ht. (in.)	HEART RATE			
				PRE-EXERCISE		STEADY STATE	
				Test 1	Test 2	Test 1	Test 2
37	24	172	72.5	96	88	165	160
38	20	151	71.0	81	88	144	148
39	20	179	72.0	97	84	158	150
40	21	185	71.0	106	82	169	156
41	26	167	68.0	91	81	170	169
42	20	174	69.0	83	92	166	164
43	20	175	69.0	80	69	149	141
44	21	161	72.5	82	81	163	163
45	20	160	70.0	75	75	148	152
46	21	189	71.5	81	76	136	131
47	21	203	73.5	94	97	147	151
48	25	181	73.0	69	53	168	155

Subject	HEART RATE				RESPIRATION RATE	
	RECOVERY (0-1)		RECOVERY (4-5)		STEADY STATE	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
37	128	140	105	107	255	230
38	101	118	85	92	275	235
39	138	125	111	98	360	335
40	143	120	121	108	280	260
41	140	136	115	105	295	320
42	136	140	113	118	300	280
43	113	95	94	83	320	315
44	122	125	98	98	225	210
45	113	102	88	92	325	320
46	106	81	83	81	240	245
47	110	113	105	107	320	285
48	133	121	99	78	320	285

(Note: Steady State Respiration Rate raw scores have been multiplied by ten to satisfy computer requirements.)





## APPENDIX F

### ANALYSIS OF VARIANCE



TABLE XVII

## ANALYSIS OF VARIANCE

## EXPERIMENT 1

STEADY STATE HEART RATE				
Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Within Groups	11	3,949.33	359.03	6.40*
Among Groups	2	429.17	214.58	
Interaction	22	737.50	33.52	
Total	35	5,116.00		
RECOVERY HEART RATE (0-1) MINUTES				
Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Within Groups	11	8,833.33	803.13	.43
Among Groups	2	74.67	37.33	
Interaction	22	1,906.00	86.64	
Total	35	10,814.00		
RECOVERY HEART RATE (4-5) MINUTES				
Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Within Groups	11	4,082.33	371.12	.24
Among Groups	2	15.17	7.58	
Interaction	22	699.50	31.80	
Total	35	4,797.00		
STEADY STATE RESPIRATION RATE				
Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Within Groups	11	147,072.22	13,370.20	3.83*
Among Groups	2	3,218.06	1,609.03	
Interaction	22	9,231.93	419.63	
Total	35	159,522.20		

$$(\alpha = .05 \quad F_{(2,22)} = 3.44)$$

\* Significant at the .05 level



TABLE XVIII

## ANALYSIS OF VARIANCE

## EXPERIMENT 2

## STEADY STATE HEART RATE

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Within Groups	11	1,121.46	101.95	
Among Groups	1	3.37	3.37	.26
Interaction	11	143.12	13.01	
Total	23	1,267.96		

## RECOVERY HEART RATE (0-1) MINUTES

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Within Groups	11	2,571.33	233.76	
Among Groups	1	6.00	6.00	.10
Interaction	11	690.00	62.73	
Total	23	3,267.33		

## RECOVERY HEART RATE (4-5) MINUTES

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Within Groups	11	875.83	79.62	
Among Groups	1	6.00	6.00	.13
Interaction	11	490.00	44.55	
Total	23	1,371.83		

## STEADY STATE RESPIRATION RATE

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Within Groups	11	83,753.12	7,613.92	
Among Groups	1	26.04	26.04	.08
Interaction	11	3,611.46	328.31	
Total	23	87,390.62		

$$(\alpha = .05 \quad F(1,11) = 4.84)$$





TABLE XIX

## ANALYSIS OF VARIANCE

## EXPERIMENT 3

## STEADY STATE HEART RATE

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Within Groups	11	2,792.31	253.85	3.43
Among Groups	2	155.06	77.53	
Interaction	22	497.61	22.62	
Total	35	3,444.97		

## RECOVERY HEART RATE (0-1) MINUTES

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Within Groups	11	8,754.75	795.89	.90
Among Groups	2	93.17	46.58	
Interaction	22	1,144.83	52.04	
Total	35	9,992.75		

## RECOVERY HEART RATE (4-5) MINUTES

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Within Groups	11	3,700.30	336.39	.19
Among Groups	2	20.06	10.02	
Interaction	22	1,141.94	51.91	
Total	35	4,862.31		

## STEADY STATE RESPIRATION RATE

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Within Groups	11	270,997.20	24,636.11	1.60
Among Groups	2	3,172.22	1,586.11	
Interaction	22	21,777.75	989.90	
Total	35	295,947.18		

$$(\alpha = .05 \quad F_{(2,22)} = 3.44)$$



TABLE XX

## ANALYSIS OF VARIANCE

## EXPERIMENT 4

## STEADY STATE HEART RATE

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Within Groups	11	2,468.13	224.37	4.08
Among Groups	1	77.04	77.04	
Interaction	11	207.46	18.86	
Total	23	2,752.62		

## RECOVERY HEART RATE (0-1) MINUTES

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Within Groups	11	4,918.46	447.13	2.04
Among Groups	1	187.14	187.04	
Interaction	11	1,010.46	91.86	
Total	23	6,115.96		

## RECOVERY HEART RATE (4-5) MINUTES

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Within Groups	11	2,924.33	265.85	2.56
Among Groups	1	104.17	104.17	
Interaction	11	446.83	40.62	
Total	23	3,475.33		

## STEADY STATE RESPIRATION RATE

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Within Groups	11	36,133.33	3,284.85	8.49
Among Groups	1	1,350.00	1,350.00	
Interaction	11	1,750.00	159.09	
Total	23	39,233.33		

$$(\alpha = .05 \quad F_{(1,11)} = 4.84)$$

















**B29852**